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Electricity and Gas Interaction: a UK Perspective and Risk Assessment

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***Abstract*—Gas-fired power stations currently generate over a third of the electricity demand of the United Kingdom (UK) and will play an increasing role in the future. At the same time the UK is becoming increasingly reliant on external supplies for gas security. The levels of physical and economic interaction between the gas and electricity systems offer a new set of risks for energy security. This paper traces the development of the UK gas industry, its growing links with the electricity sector and sets out some of the important developments in Europe and within the UK that influence UK energy security**

***Index Terms*—natural gas industry, network reliability, pipelines, power system economics, power transmission planning.**

I. Introduction

GAS fired power stations currently generate over a third of the electricity demand of the United Kingdom (UK). With the retirement of nuclear plants and the carbon emission reductions achieved by the closure of coal-fired power plants, natural gas will continue to play a large role in generation structure in the future. This growing dependence on gas for electricity generation is happening at the same time as a progressive decline in indigenous UK gas supplies. This is leading the UK to be increasingly reliant on external supplies for gas security. In addition, the increasing proportion of gas generation raises the level of physical and economic interaction between the gas and electricity networks which may imply increase security risks for electricity.

This paper will trace the development of the UK gas industry and its developing links with the electricity sector. It sets out some of the important developments in Europe that affect UK energy security but also points to the need for vulnerability assessments of the infrastructure within the UK. The paper is set out as follows. Section II gives a brief overview of the development of the UK gas industry to the present date and the possible future. Section III brings in the European dimension while Section IV looks at UK infrastructure.

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II. Gas and the UK energy industry

A. A brief history of the UK gas industry

The development of the UK gas industry broadly mirrors that of the electricity sector by developing from local production and distribution, through large scale integration in the public sector to privatisation. From the nineteenth century onwards, a series of local private and municipally-owned gas companies grew up to supply their local area with gas produced by gasification of coal ('town' gas). Following the 1948 Gas Act [1] which nationalised the industry, over 1000 producers and distributors were merged into twelve area gas boards with a Gas Council set up to overlook their operation. The Gas Council began the process of interconnecting these disparate systems to develop the national gas grid.

To meet growing demand, new sources of gas were sought and Liquid Natural Gas (LNG) shipments were delivered from the Gulf of Mexico and Algeria from 1963. At the same time, surveys of the area known as the UK Continental Shelf (UKCS) in the North Sea uncovered a plentiful untapped undersea reserve of natural gas. Extraction started in 1967 and government policy was that the resource should be used to its full potential as soon as possible to reap the maximum benefit. This policy led to the UK becoming completely self sufficient in terms of meeting natural gas demand and imports of LNG were no longer required [1]. The 1972 the Gas Council was replaced by British Gas Corporation (BGC) and all gas produced on the UKCS had to be sold to BGC. It also led to the twelve gas boards becoming regional boards meaning that they became responsible for a particular geographical area.

The Thatcher Government took its first steps towards liberalisation of the UK gas industry with the 1982 Oil and Gas Act which looked to reduce the monopoly power of BGC by allowing gas producers to supply customers directly and have third party access rights to the National Transmission System (NTS). The 1986 Gas Act returned the entire gas industry to the private sector as British Gas plc (BG) which had responsibility for transmission, distribution and supply. Despite third parties' access to pipeline infrastructure, there were complaints of inadequate competition and BG was referred to the Monopolies and Mergers Commission (MMC) in 1987. This resulted in several measures to open the market and a second review in 1993 led to the Government agreeing to open the domestic gas market to competition by 1996 [2].

After the 1995 Gas Act, BG was split up into replaced by a transport company (Transco, now National Grid), an upstream company (BG international) and a downstream company (Centrica). A new gas regulator was created (Ofgas now Ofgem) to oversee regulatory functions necessary in the new market design along with the government (DTI now BERR). The British Gas brand was retained for domestic supply but by May 1998 the entire market was open to competition with consumers able to choose their gas supplier.

B. The 'dash-for-gas'

During the late 1980s and into the 1990s, a significant shift was witnessed in the power generation sector in the UK. Coined the "dash-for-gas", Britain went from having next to no gas-fired generation to having over 14 GW of installed combined cycle capacity by 1997. The level of investment in the period between 1990 and 1995 can be seen in Fig. 1 and it shows that the change in the UK is much larger than other nations. The capacity as of 2008 stands at 27 GW [3].

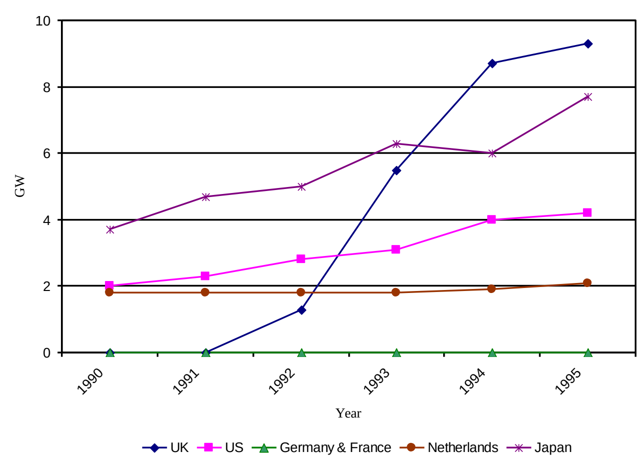

Fig. 1. Combined Cycle Gas Turbine capacity installed, 1990-95 [4]

The unusual burst of investment in Combined Cycle Gas Turbine (CCGT) technology can be attributed to a number of factors. Pre-privatisation, natural gas was regarded as too valuable a fuel to use for power generation, although modest amounts of open cycle GTs were available for peaking. The arrival of the indigenous UKCS supplies occurred simultaneously with advances in CCGT technology; prior to the 1980s, CCGT plants played a very minor role in power generation until advanced gas turbine units were developed that could achieve thermal efficiencies of 48%, making them a very viable option for investors. Coal-fired generation became unpopular due to acid rain concerns in the late 80s with companies required to fit flue gas desulphurization (FGD) to new plant, adding considerably to power plant capital and running costs. Gas-fired generation was seen as a good alternative both economically and environmentally. The changed investment conditions associated with privatisation also played a key role in the 'dash-for-gas' allowing less capital intensive CCGT to be supplied by foreign equipment suppliers into a technologically-sparse marketplace [5].

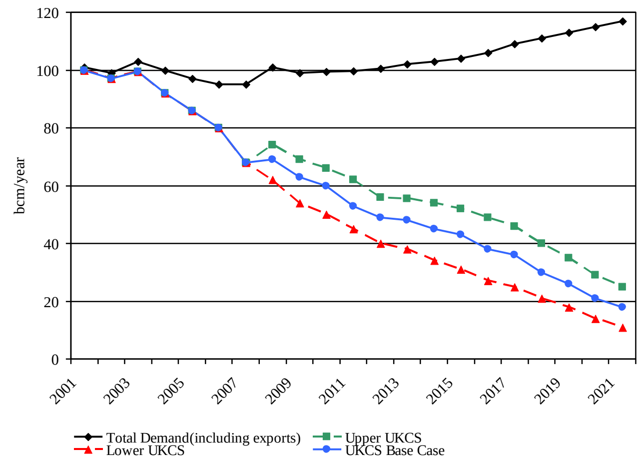

Fig. 2. Decline of UKCS natural gas production [6].

C. Decline in UKCS production

This "dash-for-gas" contributed in part to the eventual decline in UKCS natural gas production. As domestic gas consumption rose significantly, more and more gas was being drawn from indigenous North Sea supplies to meet demand. Rather than the government looking to protect and prolong supplies (as was practiced in Norway, for example), policy change in the 1980s led to the fastest possible promotion of UKCS natural gas production. In addition, following the opening of an Interconnector to Belgium (running Bacton to Zeebrugge) gas was now able to flow to the Continent when the market allowed. Britain enjoyed a period of plentiful exports of natural gas due to the low price of the gas compared to the high oil-indexed prices on the Continent driven up by the high oil prices in 2000 [7]. This also contributed to a steady decline in the UKCS reserves. Fig. 2 shows how the reserves have recently declined and projections of how they will continue to do so over the coming years.

D. Security of supply and reliance on imports

In 2006 the UK ceased to be a net exporter of natural gas and became a net importer due to the decline in indigenous supply [6]. Gas imports are currently meeting around one third of the UK's total annual demand and could rise to as much as 80% by 2020 [6]. Fig. 3 shows the increasing reliance on imports into the future in the UK and Fig. 4 shows a simplified schematic of the European pipeline network. This raises a number of questions regarding the security of gas supply into the future as the UK becomes more dependent on outside sources to meet gas demand. Indeed, a deeper interest has developed over the state and position of the liberalisation of the European natural gas market. The UK gas market is viewed as one of the most liquid markets in the world and the most liquid in Europe. This means exposing its mature, competition-orientated gas market to the less mature gas markets in Europe which may be more focused on domestic industry or national interest than on ensuring European-wide competition. The development of liberalisation in Europe is discussed in the next section.

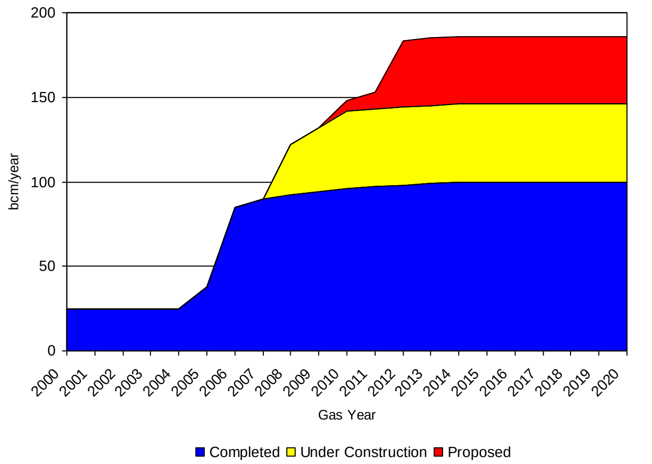

Fig. 3. Current, under construction and proposed import capacity in the UK [6].

III. The European Dimension

A. Background to the European liberalization process

Only a few countries have the advantage of having substantial natural gas reserves that are large enough to meet domestic needs and facilitate significant export to other countries. Considerable investment was needed to connect these few countries, Norway, the United Kingdom, the Netherlands and Denmark, with other European load centres via an extensive pan-European pipeline network. This then led to the development of an extremely pro-nationalistic framework, where national organisations were set up, quite often with the heavy involvement of the State, to co-ordinate the high-pressure transmission system. These national co-ordinators were also tasked with the negotiation of the various import and export transactions required to bring gas from the few production regions to the many European load centres. This background makes the harmonisation of the internal European natural gas market fraught with difficulties.

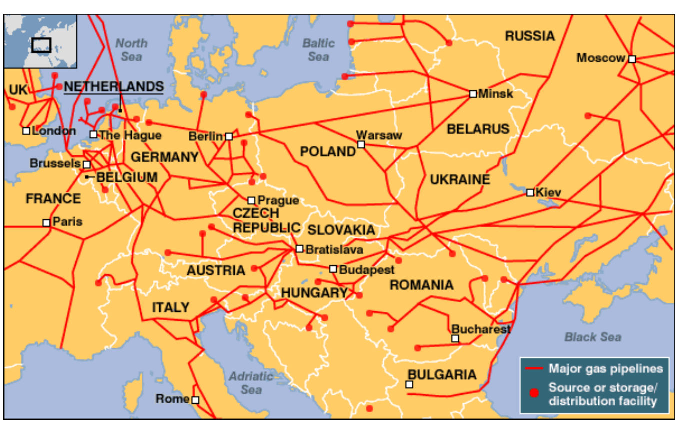

Fig. 4. Schematic of the European gas network [8].

B. First EU Gas Directive

In 1998 the EU Member States approved the first EU Gas Directive (1998-98/30/EC). This was the first and necessary step on the long road to achieving full market liberalisation within Europe. The key objective of the Gas Directive was “to provide fluidity in gas flows and improve security of supply and industrial competiveness” in Europe [9]. The directive was, however, rather restricted in its approach. It only required “appropriate and efficient mechanisms for regulation, control and transparency so as to avoid any abuse of a dominant position, in particular to the detriment of consumers, and any predatory behaviour.”[9] This was seen as rather vague and led to a wide range of interpretations by many of the Member States. There was a noted absence of any guidelines for a tariff structure or access conditions to pipelines.

C. Second EU Gas Directive

The second Gas Directive (2003-2003/55/EC) was implemented in 2003. It was to address many of the weaknesses present in the first directive and its focus became more specifically the “creation of a fully operational internal gas market, in which fair competition prevails.” It set out a number of specific changes to the running of the market [10]:

- regulated third party access to the transmission and distribution system is mandatory,
- vertically integrated players are required to legally separate monopoly business,
- the market opening timetable set down by the first gas directive was brought forward
- each member state should designate competent bodies with the function of regulatory authorities which are wholly independent of the interests of the gas industry.

D. Security of supply directive

In addition to establishing rules for a well functioning internal gas market through the first two directives, the European Community wanted to provide measures that would also safeguard an adequate level for the security of gas supply. The directive (2004- 2004/67/EC) set out certain instruments that were to be used by each Member State to enhance the security of gas supply, including [11]:

- gas supply source diversification and gas storage
- provision of pipeline capacity to enable diversion of supplies and system flexibility
- interruptible demand and back-up fuels for power generation
- domestic production
- long term contracts
- transmission system operators cooperation to coordinate dispatch
- infrastructure investment for gas imports via re-gasification terminals and pipelines.

These only serve as guidelines to the Member States. However they are required to ensure that supplies for household customers inside their territory are protected to an appropriate extent at least in the event of [11]:

1. A partial disruption of national gas supplies during a period to be determined by Member States taking into account national circumstances.
2. Extremely cold temperatures during a nationally determined peak period.
3. Periods of exceptionally high gas demand during the coldest weather periods statistically occurring every 20 years.

Although well intentioned, these measures remain open to interpretation.

E. Towards full liberalization

Regulation 1775/2005 was agreed upon in September 2005 and its main aim was to remove the remaining barriers towards achieving full liberalisation of the internal gas market. There was a need for additional technical issues to be addressed that were not in the second gas directive, in particular regarding third party access services, principles of capacity allocation mechanisms, congestion management services and transparency requirements. This regulation was met with some resistance by a few member states, because they didn't feel that the second directive had been given enough time to have its full effect but regardless of this the European Parliament added some amendments and approved it [12].

To progress further towards full *energy* market liberalization across Europe a third energy package has been announced and will be introduced to [13]:

- Treat energy and environmental issues together,
- Treat gas and electricity equally,
- Completely unbundle ownership of transport and sales,
- Create a European agency of energy regulators to monitor cross-border issues,
- Give the responsibility for energy security and market integration to member states and companies.

Although progress has been made in achieving full liberalization, it is still an ongoing process with a long way to go. As the UK enters into an era of reliance upon outside sources to meet gas needs, this will raise concerns. However, there are still matters closer to home that need to be dealt with before attention is drawn towards what is happening in Europe.

IV. UK ENERGY SECURITY

A. Security of domestic infrastructure

The UK government response to the growing reliance on imports is to focus its concerns over security of supply issues on the continent rather than on risks to domestic infrastructure. An energy review consultation published by the DTI (now BERR) on "The effectiveness of current gas security of supply arrangements" in October 2006 showed there is an over-emphasis on matters beyond our borders with no attention given to our own infrastructure security. Jonathan Stern of the Oxford Institute for Energy Studies points this out in his response to the consultation [14]:

> "*While the emphasis of future security analysis is on external threats, the evidence from the recent past... demonstrates that the main problem has been the failure of domestic commercial and regulatory framework to provide adequate security of supply"*

Several recent events have underlined the need to investigate more closely the adequacy of UK infrastructure at meeting our security of supply needs:

1. The most significant event was the Rough fire incident on February 16th 2006 which led to the tightest supply/demand balance experienced. Rough is by far the largest storage site in Britain and is the only strategic storage that can be called upon when the supply/demand balance is tight. The fire meant that the site was down for nearly 5 months. It has been put down to good fortune that the event didn't occur at the beginning of the winter in November 2005 or at the end of the winter in April/May 2006, otherwise physical rationing would have been required because there was insufficient gas to meet demand.
2. In July 2007 the CATS pipeline supplying the Teesside supply terminal on the NTS was damaged and it took three months to repair. The demand deficit had to be made up from the modest gas storage resources.
3. In February 2008 a fire at the Bacton terminal resulted in it being out of service for over a month. On its own the incident was not significant enough to cause the system balance any real problems, it certainly would have been a problem if a similar incident had occurred elsewhere on the network simultaneously.

These few incidents are used to illustrate a point, that domestic gas infrastructure is not as secure as it needs to be. With greater demand for gas into the future, more stress will be put on the system which may lead to incidents becoming more commonplace. In addition to estimating the likelihood of such events occurring, it is also essential to begin to consider the impact of them should they occur.

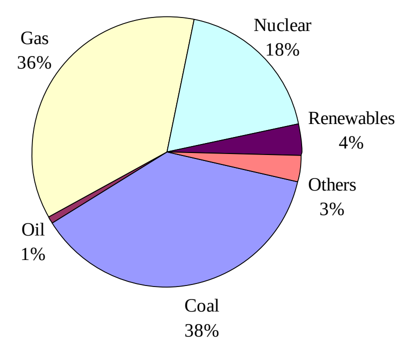

Fig. 5. Current UK generation mix [15].

With the large and growing contribution of gas-fired generation this means examining not only the gas infrastructure but also the electrical infrastructure interacting with it.

Interaction between gas and electricity networks

The growing dependence on gas for electricity generation which will only continue to rise into the future, as shown in Figures 5 and 6, means that it is now impossible to decouple the security of the electricity supply from the security of the gas supply.

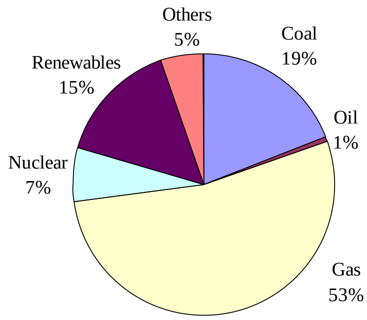

Fig. 6. Projected UK generation mix for 2020 [16].

The issues already raised in this paper will directly impact the security of the electricity transmission system.

Fig. 7. Simplified schematic of the UK NTS [17]

B. Design and operation of the National Transmission System

The National Transmission System (NTS) is owned and operated by National Grid Gas plc and it is used to transport gas that arrives via 8 input terminals to 8 Gas Distribution Networks (GDNs) operated by 4 GDN operators: National Grid Gas plc., Scotia Gas Networks plc, Northern Gas Networks Ltd. and Wales and West Utilities. Fig. 7. shows a simplified schematic of the NTS. It consists of 6,600 km of 450 – 1220mm diameter pipeline and operates at pressures ranging from 45 to 85 bar with 26 compressors that currently help maintain system pressure at the extremities. Agreement over the use of the UK gas transportation system is managed for all interested parties by the operation of a Unified Network Code (UNC). There is also a Transportation Principal Document that defines the rules and an Offtake Arrangements Document which governs the day to day agreements between the NTS and GDN system operators.

The system is designed in the steady state using daily demand and the supply/demand condition assumed for design conditions is a 1 in 20 peak day condition, which means that the system will only fail to supply forecast demand on average one year in twenty although multiple failures are allowed in that year. This is based on Composite Weather Variable (CWV) data dating back to 1928.

A “Design Margin” is applied to the steady state analysis of the system to cater for events that are not modelled within the design and which otherwise may cause failure, these events are:

- Failure of a compressor,
- Forecast error – up to the peak demand required by a Distribution Network,
- Supply Failure.

Statistical relationships have been developed industry analysts for the likelihood of these events occurring simultaneously and transient analysis is used to derive the level of support necessary in the design of the pipes to ensure there would be no failure of the system. Currently this level of support is 5% and it is applied as a flow margin during network analysis. There is also pressure cover that is used in addition to this which stipulates an elevated pressure requirement for the extremities of the system. Practically, these design requirements are met in the network through increased pipe diameter or increased power requirements for compression. With a greater stored volume of gas due the “Design Margin”, there is sufficient time to manage the system at peak demand conditions when the system is stretched and an unplanned event or incident would cause a failure of the network to maintain adequate pressure to support downstream systems. This time that is provided to manage the system could be seen as the equivalent of the N-2 standard used in electricity network design; this time is limited though to just a couple of hours. This extra time enables the System Operator (NGG) to act accordingly to mitigate the issue perhaps through the withdrawal from storage systems or by relying on the On-the-Day Commodity Market (OCM) to make up the shortfall.

In the steady state design it is naturally assumed that the profile for the directly connected and DN demands of the system are completely flat. But with increasing reliance on gas to fuel electricity generation, this assumption may no longer be enough to ensure that the separate gas and electricity transmission systems are being designed with this growing interaction taken into account. This is particularly the case when gas generation is required to operate flexibly when gas is the marginal fuel and where large volumes of wind generation is connected.

C. Combined gas-electricity network analysis

The issues mentioned in this paper show that there is a need for a detailed combined gas-electricity network scenario analysis which will investigate future network reliability into the long term. This is required to achieve a number of goals:

- Accurately model the growing interaction between the gas and electricity systems into the future such that the adequacy of the infrastructure to cope with a growing variability of daily demand from directly connected power stations is assessed
- Investigate domestic security events (such as the loss of supply routes/major pipelines) and the impact they might have on both the gas and electricity systems
- Assessment of the growing reliance upon the less liberalized gas markets on the continent and what impact certain continental security events might have on gas and electricity infrastructure

Such an analysis will require detailed information from both network operators in order to serve as actual representation of the impacts this increasing interaction will have on the real networks. The analysis will also be used to show the potential for integrated operation and planning in order to enhance fuel delivery and overall network security.

V. Conclusion

Through looking at the historical context from which the UK gas industry has evolved, this paper has shown that the UK energy sector is moving into a period of increasing uncertainty. The depletion of the UK Continental Shelf and an increased domestic demand for natural gas have raised concerns that what was once a secure national gas market, is now under threat from entering further into a less liberalized European market context. Most importantly, the UK electricity sector is also being increasingly affected due to an ever-rising reliance on natural gas for generation. It has been argued that a detailed combined scenario analysis of the UK gas and electricity networks is required to ensure the security of the UK energy supplies for the years to come.

VI. Acknowledgment

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VIII. Biographies

James Whiteford (M’08) is a PhD candidate in the School of Engineering at the University of Edinburgh. His research activity includes gas and electricity networks and energy economics.
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Professor Janusz Bialek obtained his MEng and PhD degrees from Warsaw University of Technology where he worked until 1989. From 1989 until 2001 he was with University of Durham, UK. Currently he holds the Chair of Electrical Engineering at the University of Edinburgh, Scotland. His main research interests are in the range of issues connected with liberalisation of electricity supply industry and in power system dynamics.